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SEMIANNUAL REPORT ON COMPONENT PACKAGING TECHNIQUES

1 January 1959—30 June 1959

43 p

SPACE TECHNOLOGY LABORATORIES, INC.
P.O. Box 95001, Los Angeles 45, California

TR-59-0000-00704

SEMIANNUAL REPORT

ON

COMPONENT PACKAGING TECHNIQUES

1 January 1959 - 30 June 1959

Prepared for the Air Force Ballistic Missile Division
Headquarters, Air Research and Development Command
Under Contract AF 04(647)-309

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Electromechanical Systems
Laboratory

SPACE TECHNOLOGY LABORATORIES, INC.
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Los Angeles 45, California

ABSTRACT

Because of operational difficulties, the Motorola Beacon was rejected as a test vehicle for evaluating components packaging techniques, and advanced electronic and electromechanical circuitry, studied as part of other laboratory programs, are now being considered as test vehicles.

The investigation of the dynamic absorber principle, for improved vibration protection of equipment, culminated in a new design, which represents the optimum development practical at this time.

The study of random and sinusoidal vibration resulted in the installation of a tape recording system to permit spectral analysis of the vibration data. The system can record 21 channels of information simultaneously with the use of subcarrier oscillators.

Statistical analysis of data, obtained in low-pressure electrical discharge experiments, showed possible deviation from Paschen's Law in the designer's favor.

Work on the lightweight transducer, which is both expendable and versatile, was brought to completion.

The Materials and Processes Laboratory continued experiments with various commercially available foamed-in-place plastics. Thermal transmission data were obtained, and the effects of corrosiveness on electronic materials were studied. The laboratory also began studies on microminiaturization and the state-of-the-art of electronically welded interconnections of electronic circuitry.

CONTENTS

ILLUSTRATIONS

I. INTRODUCTION

The following report discusses the progress made in the field of components packaging during the period from 1 January 1959 through 30 June 1959. The studies were begun under Contract AF 18(600)-1190 and were continued under Contract AF 04(647)-165. During the past six months, authorization was given to proceed with the study of components packaging techniques under Contract AF 04(647)-309.

II. SELECTION OF TEST VEHICLE

According to the Performance Studies Chart of Project Plan 165-21, the first task to be accomplished was the selection of Test Vehicle No. 2. STL considered products of various manufacturers with regard to the eight criteria stated in the project plan. For a time, the Motorola AN/DPN-54 Transponder (Beacon) appeared to fulfill these criteria because it presented interrelated problems of electrical performance, structural integrity, and thermal adequacy. For example, the microwave portions, used in receiving and transmitting, created severe environments which offered a challenging study of over-all reliability. At the same time, correction of some of the problems of microwave components involved the study of improved component design, and the logic and decoding circuitry provided a vehicle for the exploration of fabrication techniques. Finally, the unit as a whole offered opportunity for exploration into all the areas suggested by the project plan and pertinent to integration of packaging study.

However, operational difficulties reduced the effectiveness of this transponder as a test vehicle. The microwave and modulation components were expensive and required a long lead time for procurement. The latter fact interrupted the study of the problems presented by the needed component. Then, too, the close liaison required for optimum laboratory efficiency would be expensive and time-consuming because of the distance between STL and Motorola, Inc. in Phoenix.

Confronted by these difficulties in relationship to the Motorola Beacon, STL Research and Development personnel began to investigate packaging

techniques for typical electronic and electromechanical circuitry, being developed under other laboratory programs, as possible test vehicles.

III. DYNAMIC ABSORBER INVESTIGATION*

As suggested in the last semiannual report (see Reference 1), the use of a dynamic absorber seemed to offer the best solution to the problem of controlling circuit board vibration, which eliminates fatigue failures in leads and joints of electronic components. For the past six months, experiments with circuit boards have continued, and a new design for the vibration absorber was adopted (see Reference 2). This design was chosen after consideration of three types of absorbers. The first employed a method of sliding mass on a stem, and it was found that the amount of damping was difficult to control, since the damping was affected by wear on the stem. A second design embedded a mass in sponge rubber. But it was found that heating reduced the strength of the rubber, causing fatigue failure. The present design (Figure 1), consisting of thin acrylic tube closed at both ends, houses two compressed coil springs. These, in turn, are separated by a steel ball. In addition to the ball and the springs, the tube is partially filled with a silicone oil. Clearance between the ball and the tube allows the oil to pass to either side of the ball when the ball is in motion, the oil damping the motion of the ball. The circuit board with the absorber in place is shown in Figure 2.

In controlling vibration, it is known that the vibration transmission through a circuit board from its support to any given component (say, at the antinode of the board) may be altered by changing the board material, the board thickness, or the position and rigidity of the supports. Generally, however, all three of these changes also affect the vibration resonant frequency at which the maximum vibration Q occurs, without materially affecting the Q. The vibration absorber, on the other hand, reduces the maximum Q without significantly altering the resonant frequency. If, for instance, the fundamental resonance frequency of the circuit board is optimum from the standpoint of component part fragilities, it may be necessary to reduce Q while holding the resonance frequency the same.

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*For additional information on this subject, see Reference 5.

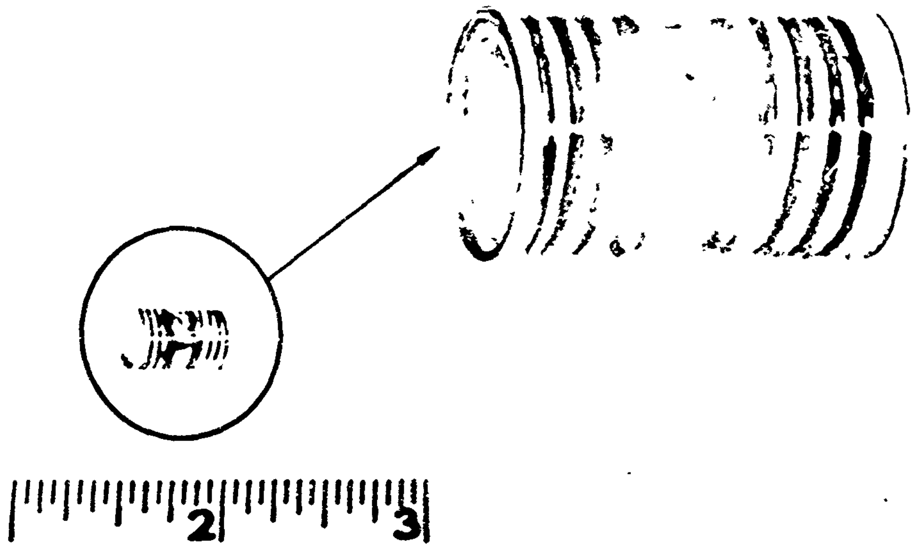


Figure 1. Vibration Absorber System.

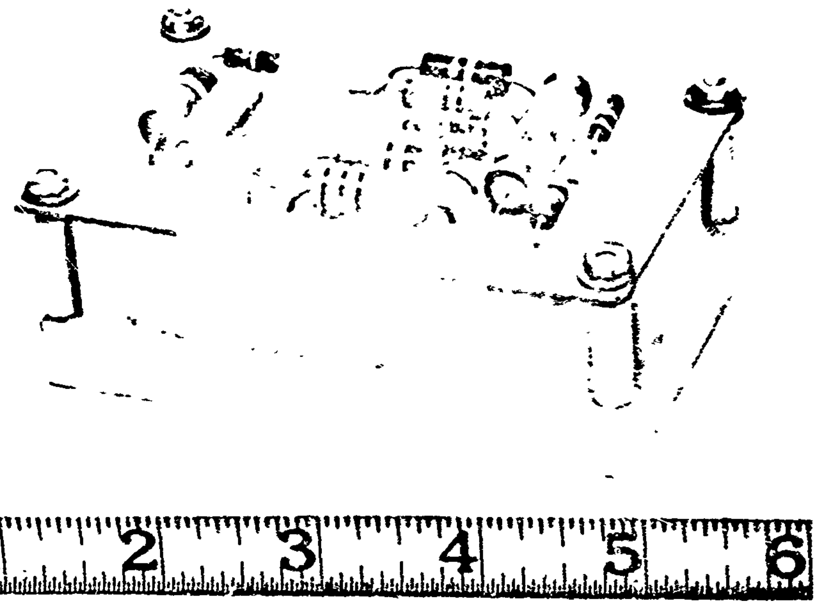


Figure 2. Circuit Board With Vibration Absorber Attached.

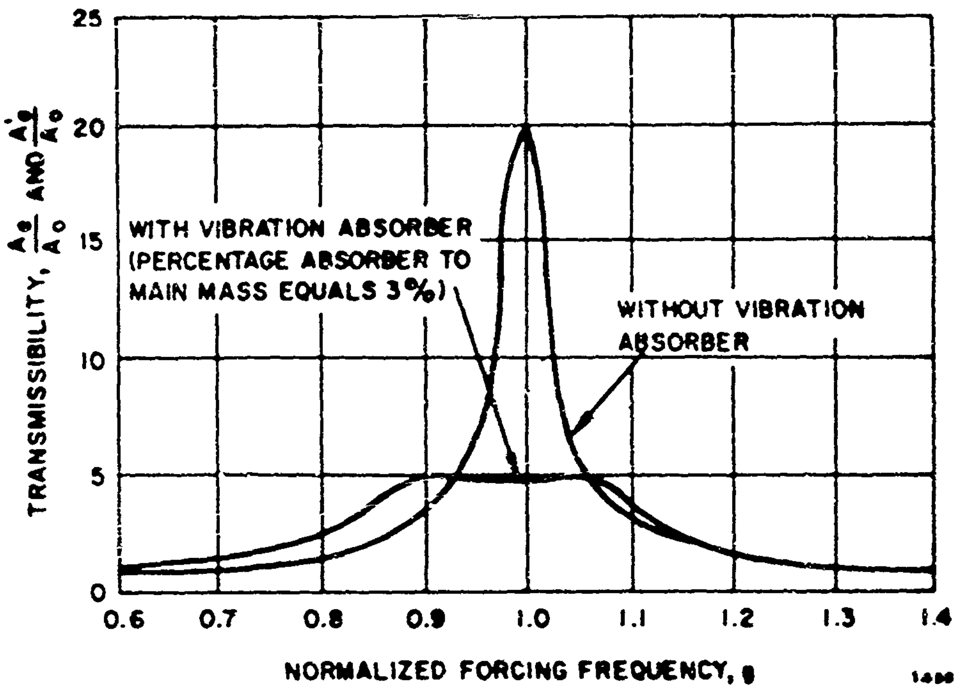


Figure 3. Transmissibility Versus Normalized Forcing Frequency Plot for Circuit Board With and Without Absorber System.

To demonstrate the effectiveness of the dynamic absorber design, vibration transmissibility measurements were made with and without the absorber in place on a circuit board. The experiments showed that an absorber system having a mass comparable to that of a subminiature component part can very appreciably reduce the Q of a circuit board, and thus provide an improved vibration environment for the board and mounted parts. The performance plots based on these experiments (Figure 3) illustrate graphically a 400 percent reduction in transmissibility at the expense of only 3 percent increase in weight.

With regard to circuit boards, the fundamental frequency in most designs is between 100 and 300 cps. The lowest resonant frequencies are the most severe because displacements are much larger. Displacement increases inversely with the square of the frequency. Therefore, if the frequency is decreased by one-half, displacement is increased by four times. This increases the tendency to damage the equipment. It is these lower resonant frequencies that the absorber may be employed to control. And if these may be controlled,

the higher modes are of no particular consequence since the corresponding deflections become very small.

The dynamic absorber cannot nullify the effects of poor design. Consequently, the absorber principle must be seen within the larger context of design. A poorly designed circuit board, for example, may have its fundamental resonance at 50 cps and may have this "taken out" by the vibration absorber, but it may still incur damage from the third mode resonance. However, if the absorber principle is used in conjunction with good design, evidence indicates improvement of transmissibility measurements at the higher modes, and, as a result, less stress on the components.

Project plans to consider the nonlinearity of dampers, suggested in the last semiannual report, were abandoned. The present system, assumed to be linear, was considered to be sufficient, and the existence of nonlinearity was believed to be insignificant. Consideration of the nonlinearity of the spring could not put the present system much in error. On the other hand, the nonlinearity of the damper would put the system error on the conservative side. The findings in regard to the absorber are, therefore, considered complete.

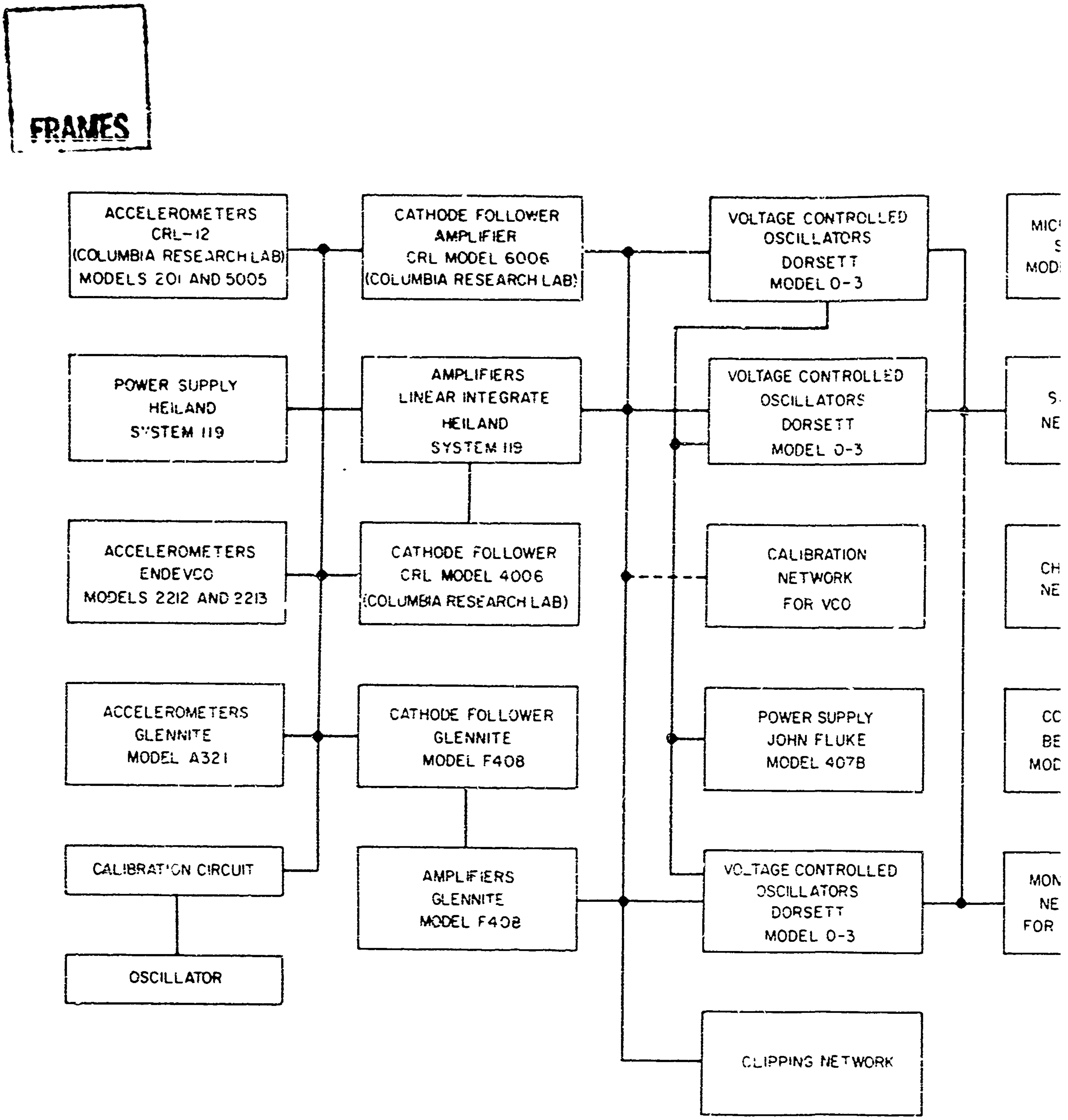
The obvious application of the dynamic absorber is to circuit boards. For other types of structures, gyros,or relays, it is of little use. Ready-made absorbers may be developed covering a given range of absorber mass, natural frequency, and damping ratio, and, therefore, would be available for circuit boards and for other electronic assemblies. Where vibration control must be supplied to existing hardware, the vibration absorber provides the best solution. The same is true in situations where altering the path of transmission is undesirable or impractical as, for example, with circuit boards which have already been tooled for specific needs. However, the absorber offers no panacea for problems of vibration; the contractor must not rely upon it as a crutch in lieu of poor.design.

IV. RANDOM VERSUS SINUSOIDAL VIBRATION

A better understanding of the concept of severity equivalence is of great importance to the design and testing of electronic equipment as it is used in ballistic missiles. There exists an obvious difference in the behavior of a structure when it is subjected to random and sinusoidal vibrations. A study program (see Reference 1) concentrating on this difference is being conducted by employing typical electronic packages designed for missile installation. The study consists of relating discrete frequency vibration response to white Gaussian noise vibration response within the above-mentioned equipment. The damage potential is construed from rms acceleration measurements made at the support of sensitive electronic component parts within a number of equipment packages. The results of this study are expected to demonstrate to what degree sinusoidal vibration can be substituted for random vibration in flight-proofing equipment. Based on these projected results, test specifications, as well as the design of hardware, may be improved. To accomplish the objectives of the program, a system was required which would simultaneously record a maximum of 21 channels of information in a form in which the information could be manipulated by current data handling devices.

Such a system has been designed and built at STL during the past six months (see Figures 4 and 5). This particular system, selected on a basis of cost, is basically an FM telemetering setup. It will record any vibrational signals within the frequency range of 1 to 2100 cps with an amplitude accuracy of 5 percent. The linearity error at a discrete frequency is only 2 percent. The lower frequency limitation is imposed by the cathode follower amplifiers and their associated accelerometers. The upper frequency is imposed by the voltage-controlled oscillators and by the discriminators' low-pass filters. The system can operate within 1 hour, including a warm-up period of 40 minutes. Also, a manual of operation for the system, which should facilitate the solving of maintenance problems, has been developed.

In preparation for definitive tests, exploratory measurements were made on a test specimen. These measurements consist of Q readings (Figure 6) for



FRAMES
ACCELEROMETERS
CRL-12
(COLUMBIA RESEARCH LAB)
MODELS 201 AND 5005
CATHODE FOLLOWER
AMPLIFIER
CRL MODEL 6006
(COLUMBIA RESEARCH LAB)
VOLTAGE CONTROLLED
OSCILLATORS
DORSETT
MODEL 0-3
POWER SUPPLY
HEILAND
SYSTEM 119
AMPLIFIERS
LINEAR INTEGRATE
HEILAND
SYSTEM 119
VOLTAGE CONTROLLED
OSCILLATORS
DORSETT
MODEL 0-3
ACCELEROMETERS
ENDEVCO
MODELS 2212 AND 2213
CATHODE FOLLOWER
CRL MODEL 4006
(COLUMBIA RESEARCH LAB)
CALIBRATION
NETWORK
FOR VCO
ACCELEROMETERS
GLENNITE
MODEL A321
CATHODE FOLLOWER
GLENNITE
MODEL F408
POWER SUPPLY
JOHN FLUKE
MODEL 407B
CALIBRATION CIRCUIT
AMPLIFIERS
GLENNITE
MODEL F408
VOLTAGE CONTROLLED
OSCILLATORS
DORSETT
MODEL 0-3
OSCILLATOR
CLIPPING NETWORK

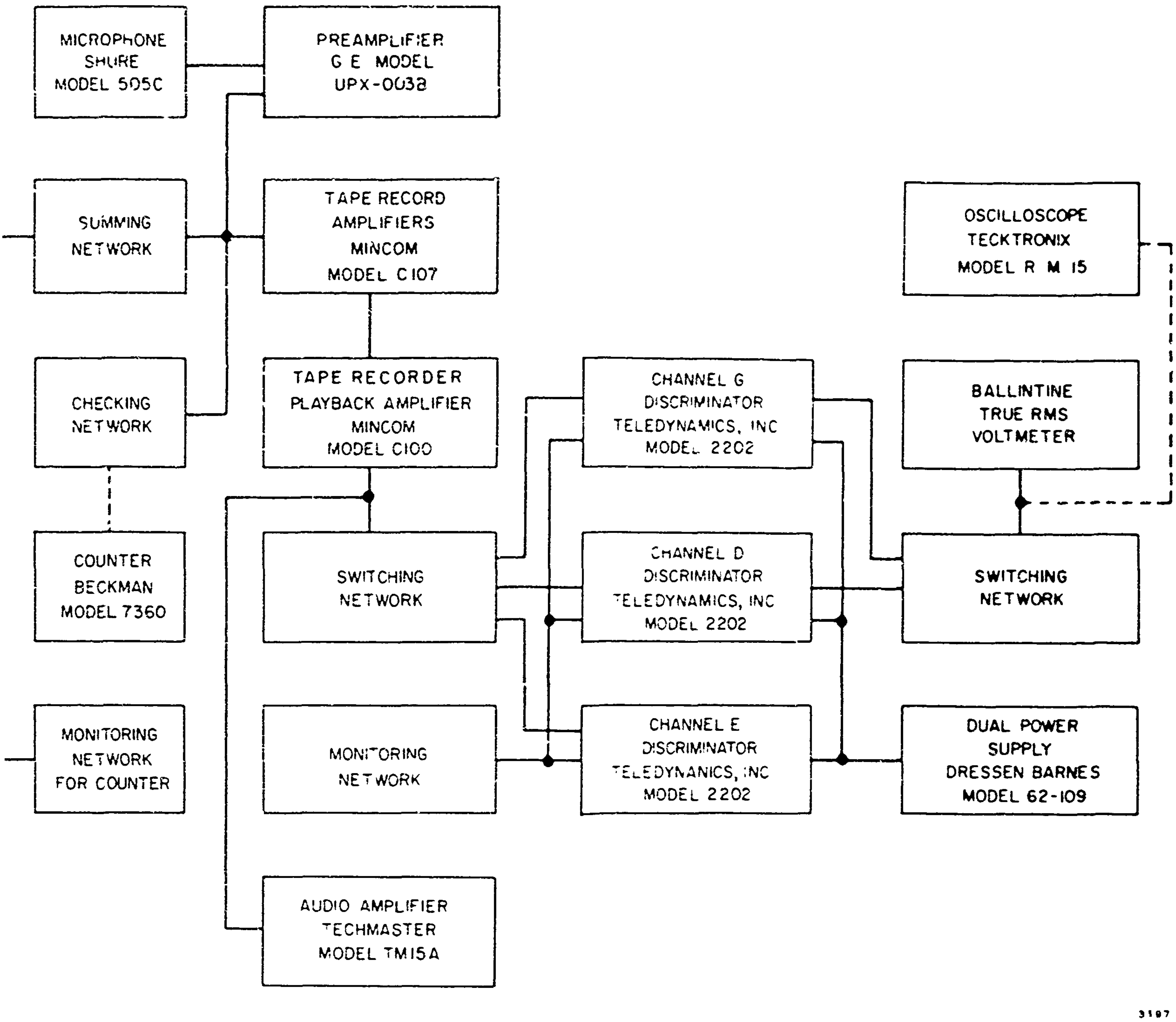


Figure 4. Data Acquisition System Used in Vibration Equivalence Program.

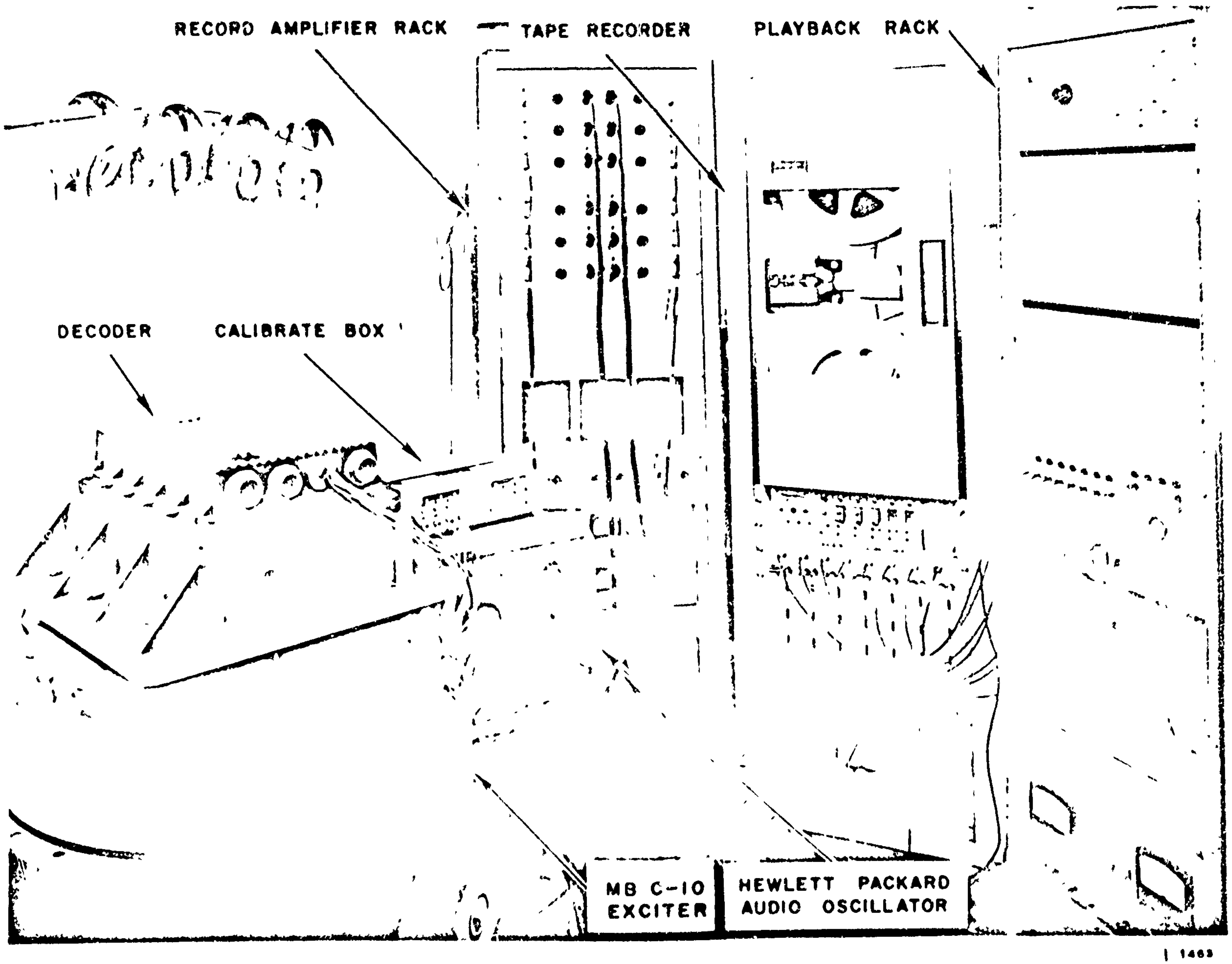


Figure 5. System for Monitoring and Recording 21 Channels Simultaneously.

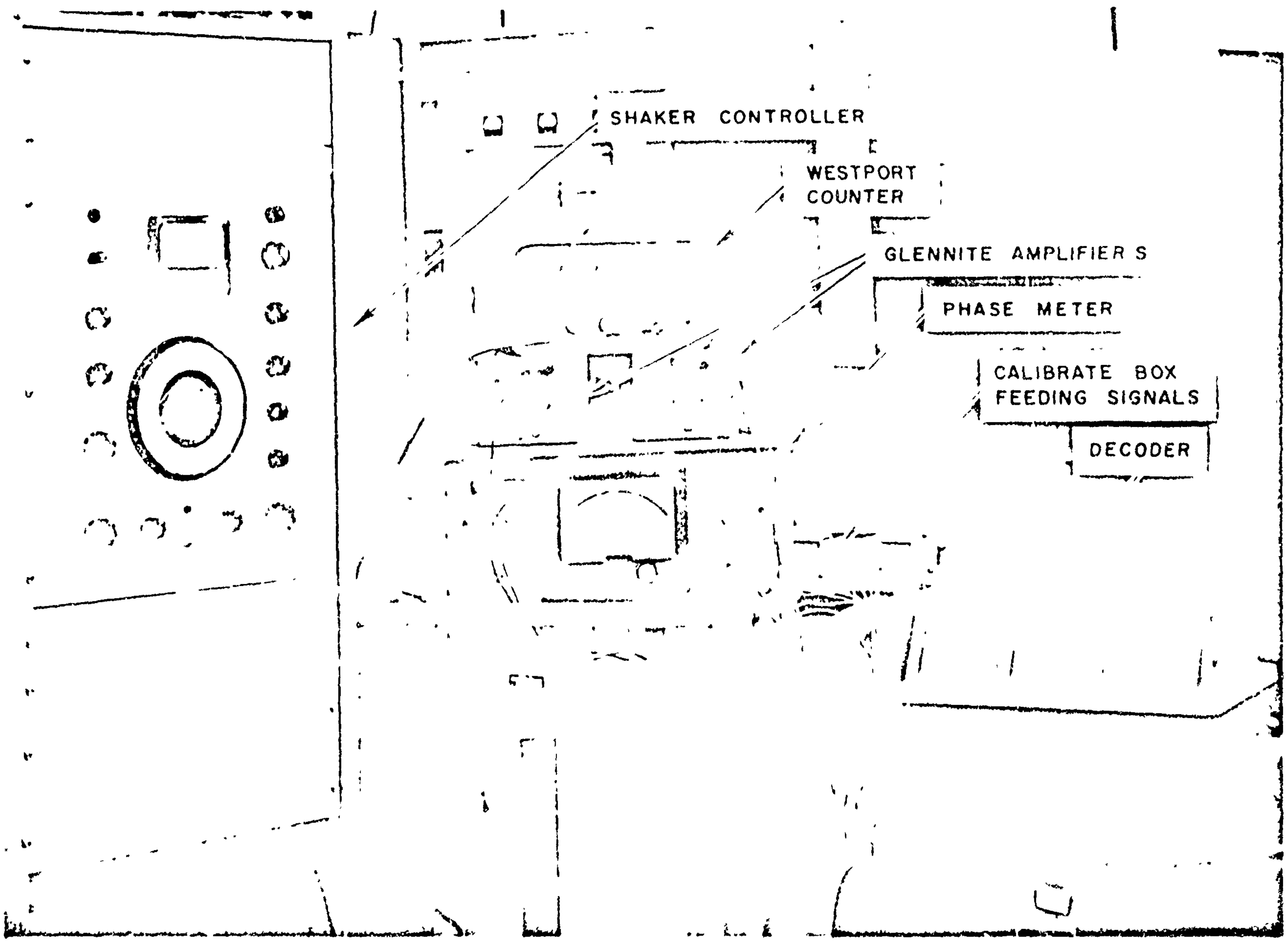


Figure 6. Setup for Vibration Measurements.

various internal package locations (Figure 7). After these measurements, the specimen was subjected to the following vibration environments, each of which simulated environmental specifications now in use for ballistic missiles:

a) A single frequency sweep for three amplitude levels
b) A white Gaussian noise for three amplitude levels.

During the specimen's encounter with these different environments, all monitoring locations within the package were simultaneously recorded.

V. LOW-PRESSURE ELECTRICAL DISCHARGE

Studies of the problem of high voltage arcing with uninsulated wiring at high altitudes were initiated. As reported in the last semiannual report, a literature survey (Reference 3) led to the recommendation that 200 volts be considered as the safe maximum voltage for bare conductors. This recommendation was based on the fact that the cathode fall potential of lead (a constituent of solder) is 207 volts. This being the lowest voltage at which a discharge utilizing a lead cathode could be sustained, the voltage at which the discharge would be initiated would then be somewhat higher. The cathode fall potential of lead is the lowest for all materials commonly used in missile applications.

The literature survey also determined the direction of the experimental stage of investigation. The objectives of the laboratory research were to:

a) Determine if statistically significant deviations from Paschen's Law could be detected by properly designed test

b) Find if such deviations would reduce the voltage necessary for producing electrical discharges, thus invalidating the predictions of Paschen's Law

c) Ascertain the effect of humidity upon the voltage necessary to initiate an electrical discharge

d) Determine the effect of surrounding conductors upon the path of the discharge.

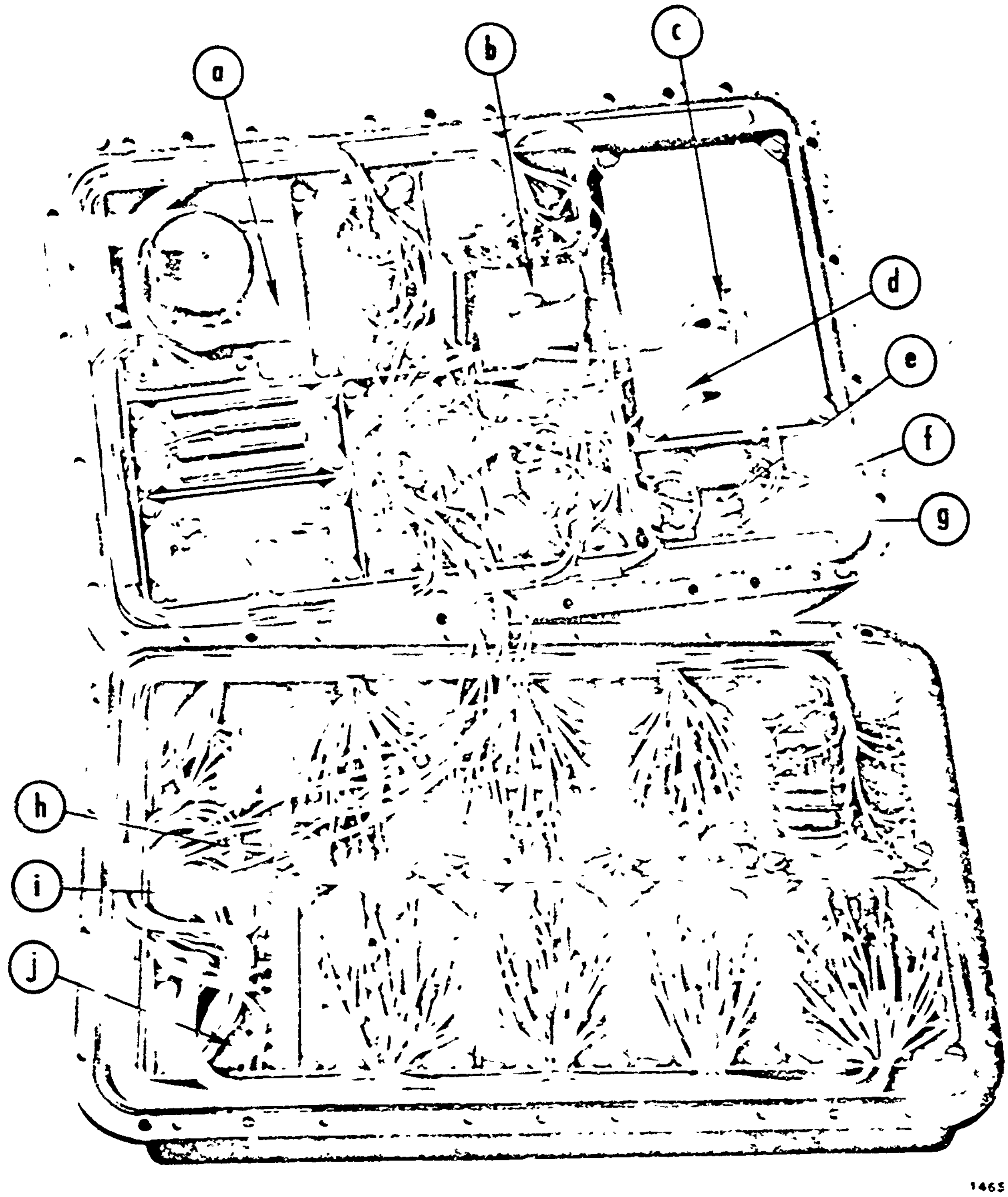


Figure 7 STL Decoder (Package C).

The letters a through j indicate accelerometer locations.

Paschen's Law states that the sparking voltage for a uniform electric field is, within certain limitations, a function only of the product of the gas pressure and gap distance, or $V_s = F(pd)$. Paschen's Law is based on the sparking criterion first postulated by Townsend. This criterion is that $\gamma\epsilon^{\alpha d} = 1$ for an electrical discharge to be initiated, where:

γ = average quantity of electrons emitted from the cathode for each positive ion bombarding the cathode

α = the number of new pairs of ions formed by collision per unit distance of travel by an existing free electron

d = the distance between electrodes.

Now Paschen's Law is postulated on a uniform electric field, which can be produced only by infinite, parallel-plane conducting surfaces. Stainless steel electrodes in the shape of Rogowski surfaces simulate this condition by producing a uniform electric field in the central region between electrodes, edge effects being minimized by the curvature of the electrodes. By use of the Rogowski surface electrodes, data were gathered for both the right and left branches of the sparking voltage curve (Figure 8). Sparking voltages were observed at various combinations of pressures and gap distances.

Paschen's Law may be stated in a more general form: $V_s = F(p^m d^n)$. This may in turn be written $p^m d^n = G(V_s)$. Then, holding V_s constant, we may write

$$m \log p + n \log d = K ,$$

where

$$K = \log G(V_s) = \text{a constant.}$$

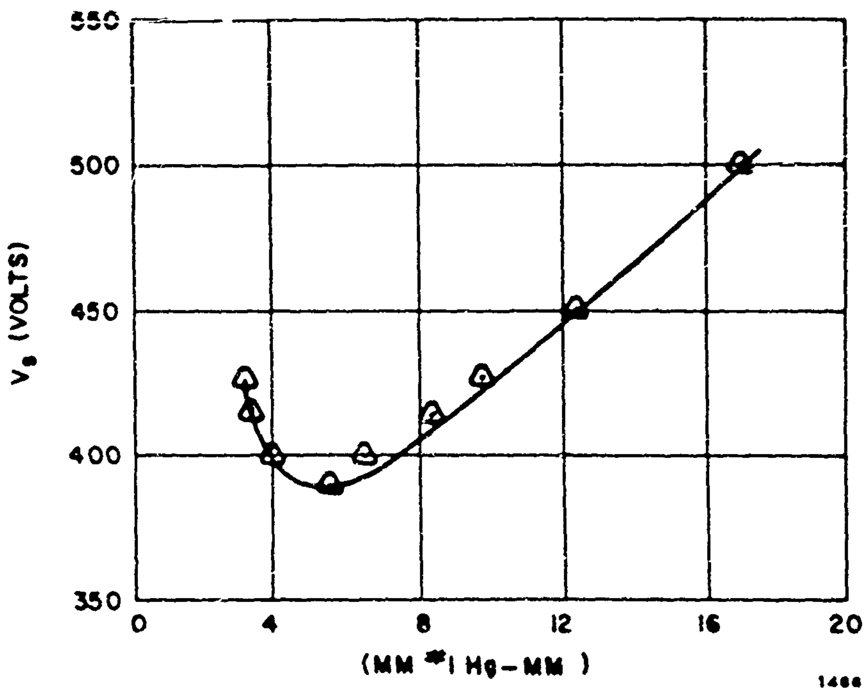


Figure 8. Breakdown Voltage Curve in Dry Air Using Stainless Steel Electrodes Obtained in STL Laboratory.

If m and n are constants, this is an equation of a straight line. Solving for log p, we find the slope of the straight line to be -n/m:

$$\log p = -\frac{n}{m} \log d + \frac{K}{m}$$

This is illustrated in Figure 9, in which log p is plotted as a function of log d. If Paschen's Law holds, n should equal m, and the resulting curve should be a straight line with a slope equal to -1. If deviations occur, the slope is not equal to -1.

Solving for log p, Paschen's Law may be checked statistically. The following null hypothesis and its alternative are stated:

$$H_0 : \frac{n}{m} = -1$$

$$H_1 : \frac{n}{m} \neq -1$$

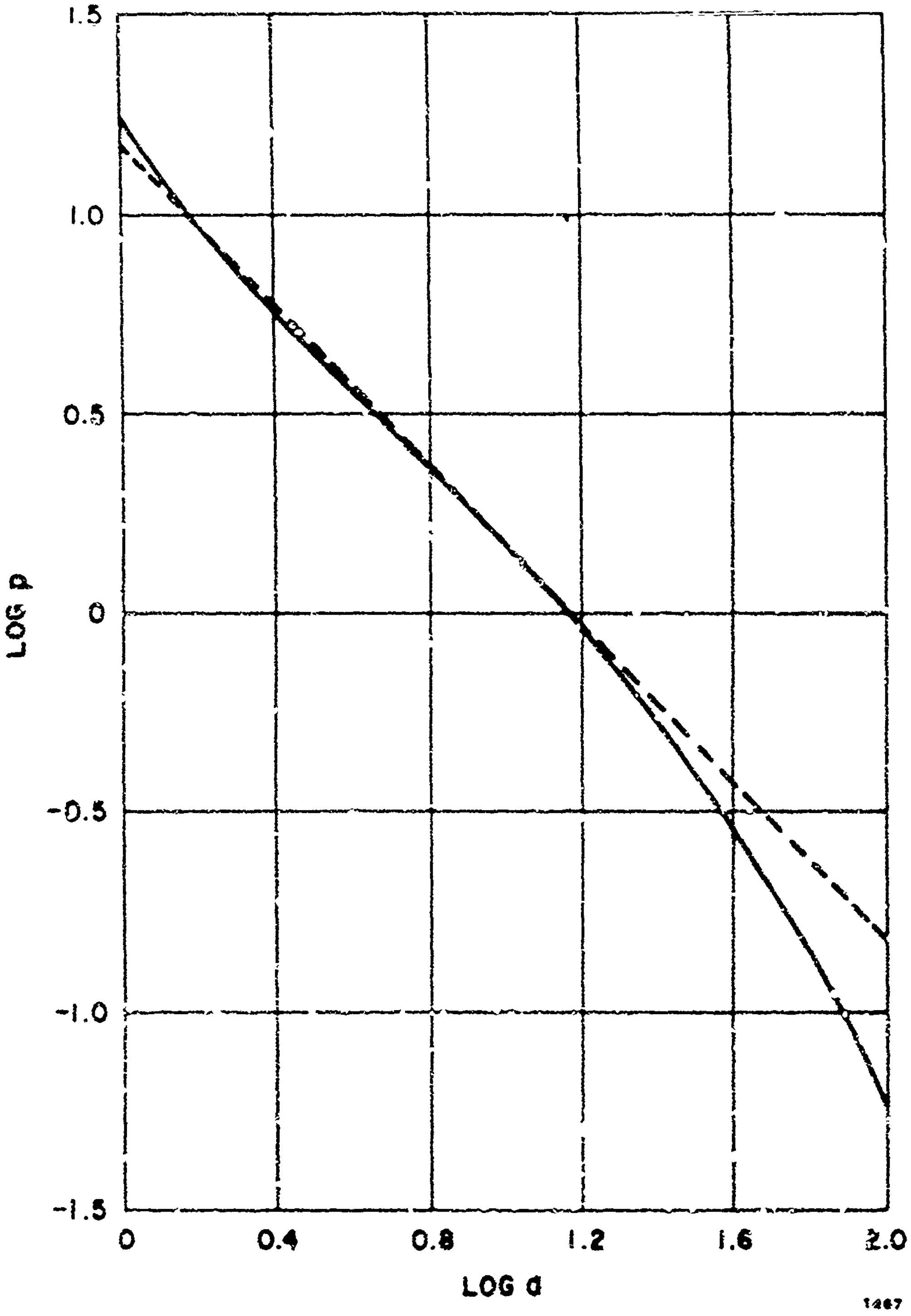


Figure 9. Regression Analysis for Log d Versus Log p.

The dotted line represents the straight line predicted by Paschen's Law; the solid curve was computed from a sample of actual data, using the method of least squares.

If the absolute value of n/m is greater than 1, the deviation from Paschen's Law will be in the designers' favor. That is, a greater voltage will be required to cause spark-over than that predicted by Paschen's Law. Preliminary analysis of some sample data indicates that this may be the case. A curve statistically fitted to this sampling of test data, and a straight line of slope equal to -1 are both plotted in Figure 9. The general slope of the curve is greater than that of the straight line predicted by Paschen's Law. However later analysis of the total test data may not show this deviation.

Many variables must be accounted for in applying Paschen's Law, for example:

a) Composition of gas
b) Surface material of the electrodes
c) Condition of the surfaces
d) Geometry of the electrodes and electric field
e) Polarity of the applied voltage
f) Temperature of the electrodes
g) Irradiation of the electrodes by ions or photons.

Most of these variables are accounted for in the previous equations by the Townsend symbols α and γ, and all affect the problem of voltage spark-over. For this reason, electrodes of various shapes and materials were used during experiments. Rogowski surfaces, already discussed, and seen in Figure 10, made of stainless steel; pointed electrodes, also of stainless steel, Figure 11; and for the long gap discharge chamber, spherical brass electrodes.

At atmospheric pressures, electrical breakdown tends to occur more readily between sharp electrodes than between blunt electrodes. However, experiments at low pressures showed that a greater potential difference was necessary to establish a discharge between pointed electrodes than between Rogowski surfaces.

Using the Rogowski surface electrodes, no major effect due to changing of polarity was noted.

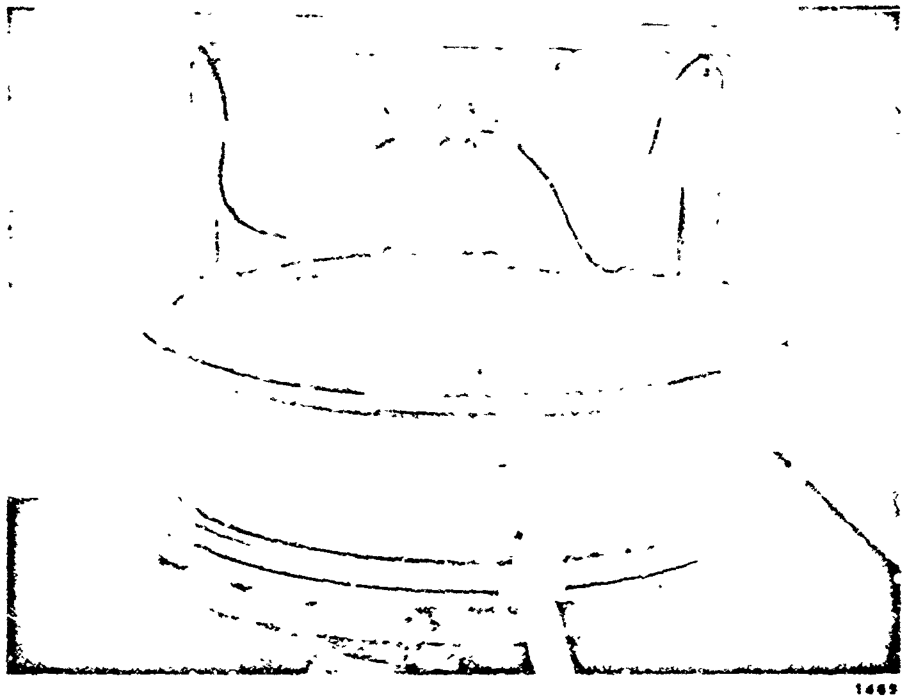


Figure 10. Rogowski Surfaces.

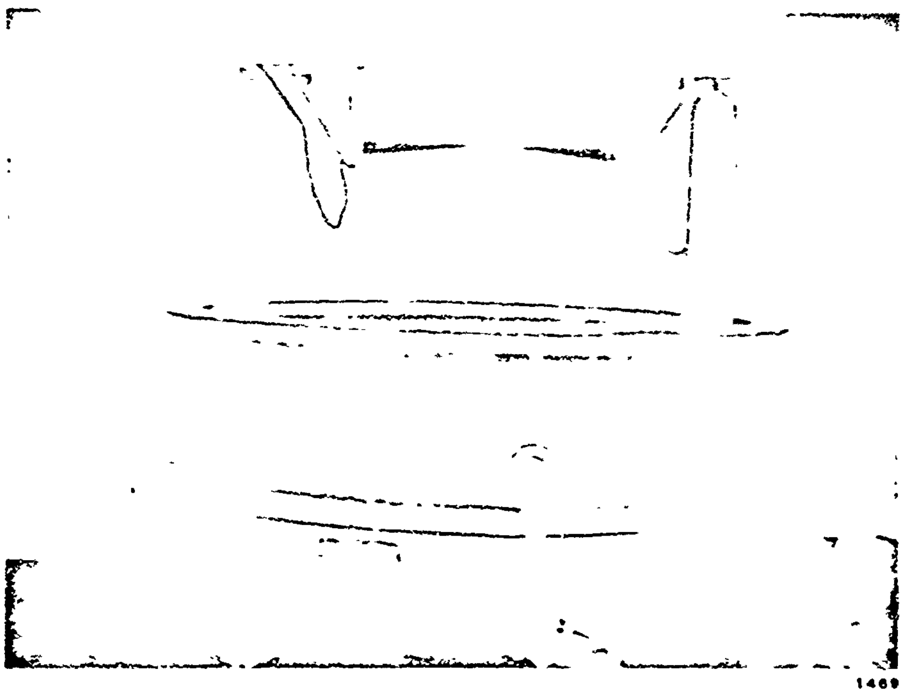


Figure 11. Pointed Electrodes.

Data were obtained to determine the effect of water vapor on the sparking voltage. It was determined that the minimum of the sparking voltage curve was decreased for humid air The minimum sparking voltage was reduced from 385 volts to 335 volts because of the addition of water vapor.

These findings agreed with those published earlier in both Europe and America, where experiments were performed in areas with relatively high humidity in which the minimum voltage was found to be about 327 volts. It seems definitely established, then, that a variation in the number of water ions in a gas appreciably alters the minimum spark-over voltage.

The long gap discharge experiment (see Figures 12 and 13) utilized two electrodes inside a conducting shell, simulating bare conductors inside any conducting enclosure, such as a ballistic missile. The purpose of this experiment was to demonstrate that, as predicted by Paschen's Law, electrical discharges may sometimes be initiated across a long rather than a short gap, even when both are available. As expected, the long gap was preferred at lower, and the short gap at higher pressures. At intermediate pressures, the gap chosen by the discharge was not predictable. The procedure involved in this experiment is detailed in Reference 4.

VI. LIGHTWEIGHT TRANSDUCER

Because of the intense vibration accelerations to which missile electronic equipment may be subjected during initial flight, considerable emphasis must be placed on attaining a competent structural design which will enhance component and/or circuit reliability. Knowledge gained from acceleration measurements, performed within an assembled package, are therefore essential to describe the vibrational environment encountered by mounted components.

To determine areas where undesirable dynamic behavior exists in electronic packages, an accelerometer can be used for monitoring. The number of desirable monitoring positions varies considerably, depending on the size and complexity of the contained electronic circuitry. As electronic equipment becomes miniaturized, weight, size, and shape of an accelerometer

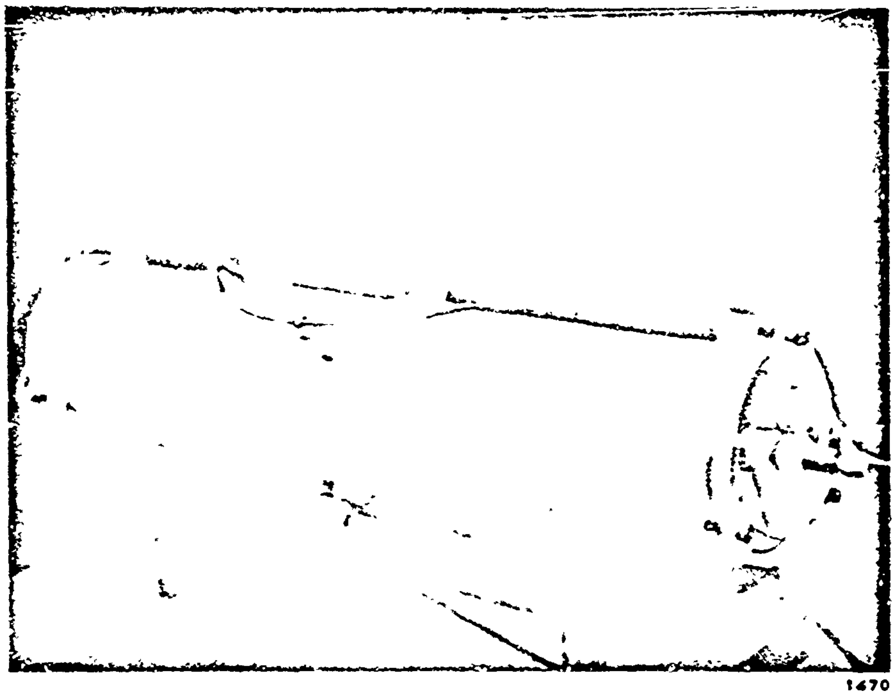


Figure 12. Long Gap Discharge Chamber.

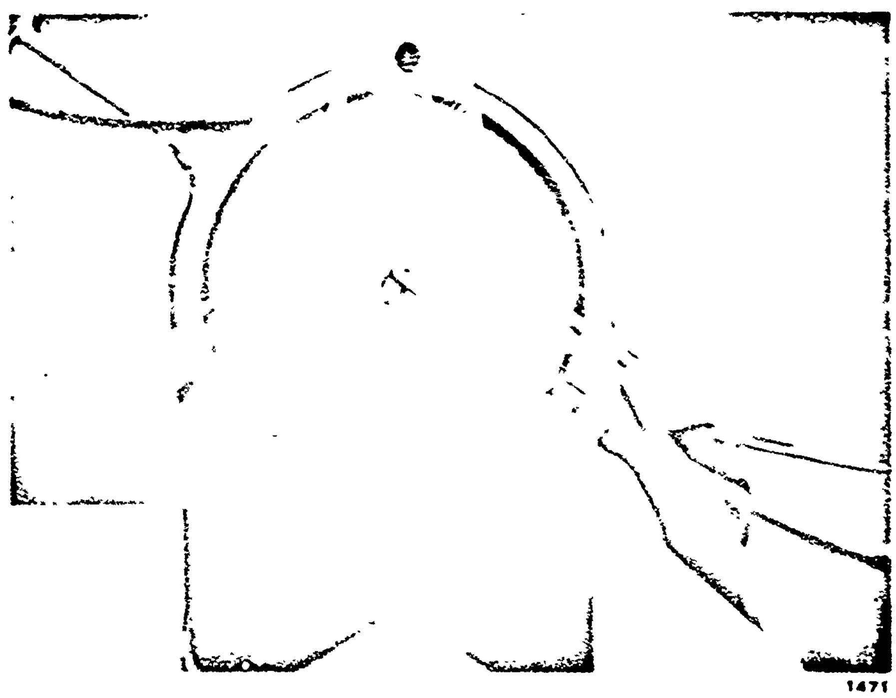


Figure 13. Glow Discharge as Seen Through Transparent End of Discharge Chamber.

become critical when flexibility of selecting monitoring positions is desired. In certain applications, the weight of the accelerometer becomes an appreciable part of the weight of the item under examination, which consequently invalidates the test data.

Once sufficient dynamic behavior data have been acquired, it would be preferable to allow the accelerometer to remain in the equipment, thus eliminating the time and expense involved in disassembly, reassembly, and retesting of the equipment when reclaiming the measuring device from "hard to get at" locations. To permit this, there is a definite need for a small, expendable, lightweight vibration transducer which may be used for exploratory probing. As reported in the last semiannual report, accelerometers presently available on the commercial market are too expensive for use as a "throw-away" item.

To develop a lightweight transducer which would overcome and satisfy the above limitations and requirements, experiments were conducted using the cantilever beam construction with the hope of obtaining a usable item. Results attained at this point were acceptable within limits, but two problems persisted at the time of the last semiannual report: distortion and frequency response.

By using a filter between the transducer and the recording meter, it was felt that the alleviation of the aforementioned difficulties was possible. Considering the low frequencies involved, an RC filter was built. This filter was designed with the following attenuation characteristics:

Frequency of normalization:	30 cps	0% attenuation
	1000 cps	20% attenuation
	2000 cps	50% attenuation

Information derived from various tests on transducers discussed in the last semiannual report was used to arrive at the necessary attenuation. An amplifier was inserted between the filter and the metering equipment. The cathode follower acts as a buffer stage for the transducer output. A block diagram of this arrangement is shown in Figure 14. Figure 15 represents the calculated action of the filter and the compensated response when used in conjunction with a transducer.

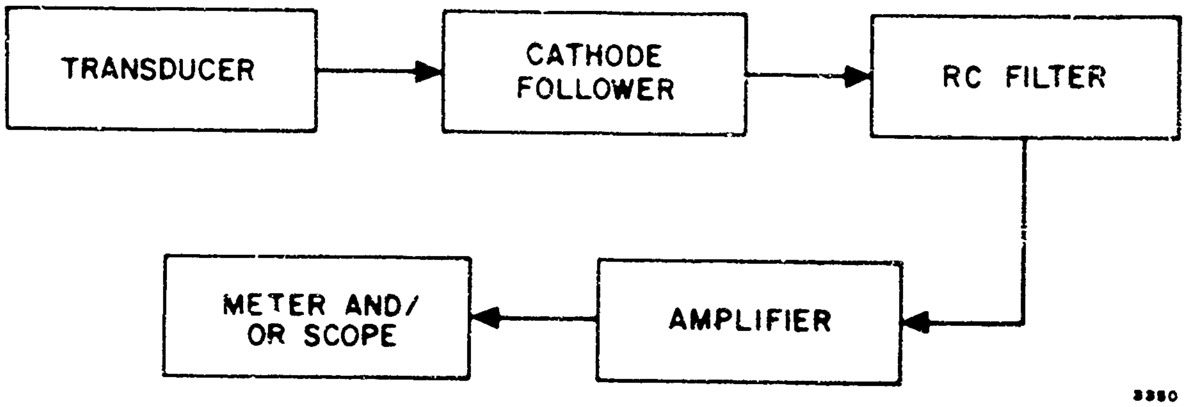


Figure 14. Block Diagram of Compensated Response Network.

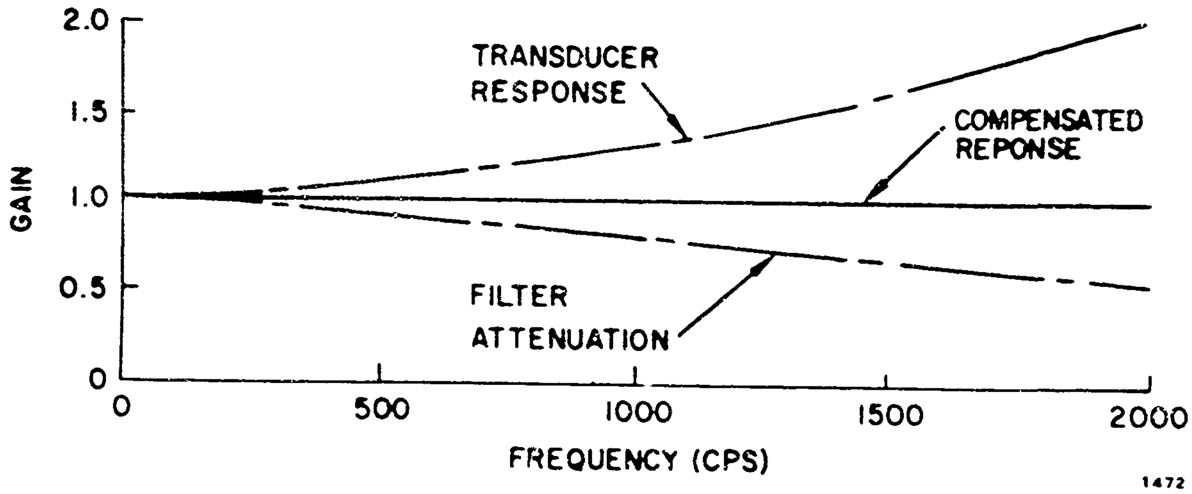


Figure 15. Graph Showing Calculated Action of Filter and Compensated Response When Used in Conjunction With Transducer.

The latest transducer design has a response starting at a particular value at 30 cps and increases to approximately twice that value at 2000 cps. The filter action is shown as having a frequency response in opposition to that of the transducer frequency response. When the transducer output is filtered, the compensated response output results. Note that the graph has linear frequency graduations. This was done to observe this portion of the frequency range in greater detail.

During this report period, higher priority projects made it necessary to discontinue using the MB vibration table as the driving exciter. A small Calydine vibration table (Figure 16) was substituted. Because of the construction of the Calydine table, mechanical resonances occurred between 200 and 600 cps, invalidating the data over this frequency range. Small resonances occurred at other frequencies, which accounts for the rapid variation that may be seen in the data obtained from this shaker. To ensure that the information recorded was obtained at frequencies of minimum distortion, two commercial accelerometers were placed on either side of the test transducer, as shown in Figure 17, to indicate resonances which were occurring in the supporting structure of the armature. These data were used to indicate favorability of approach only. For final data, a precision Goodman instrument shaker was used, utilizing a secondary standard Endevco accelerometer as a monitoring device for the input excitation.

As shown in Figures 18 through 22, results from the compensated response network show that the anticipated output and the actual test data compare favorably. In Figure 18, the compensated output shows a variation of from 0.8 to 1.8 db, even though the transducer response increased above +4 db. Figures 19, 20, and 21 show the compensated response variation to be low, while Figure 22 shows it as varying from -1.8 to +1.8 db.

There were, however, disadvantages with the filter in that it did not sufficiently reduce resonant distortion, and did not vary in characteristics, which are necessary in order to obtain a constant response between transducers. A variable filter can be easily made, but must be calibrated with a particular transducer. Consequently, then, this approach did not fulfill expectations.

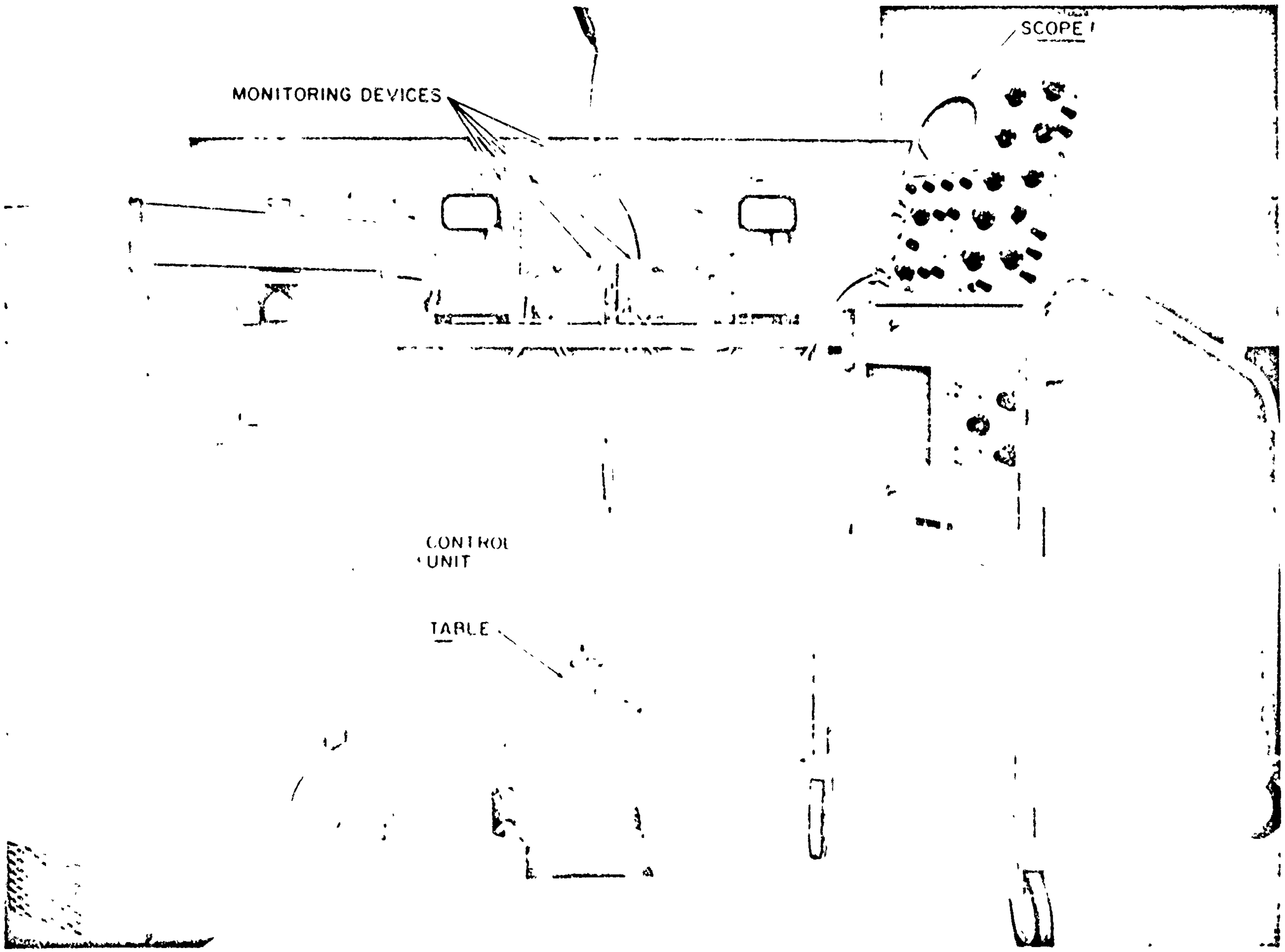


Figure 16. Calydine Table With Related Equipment.

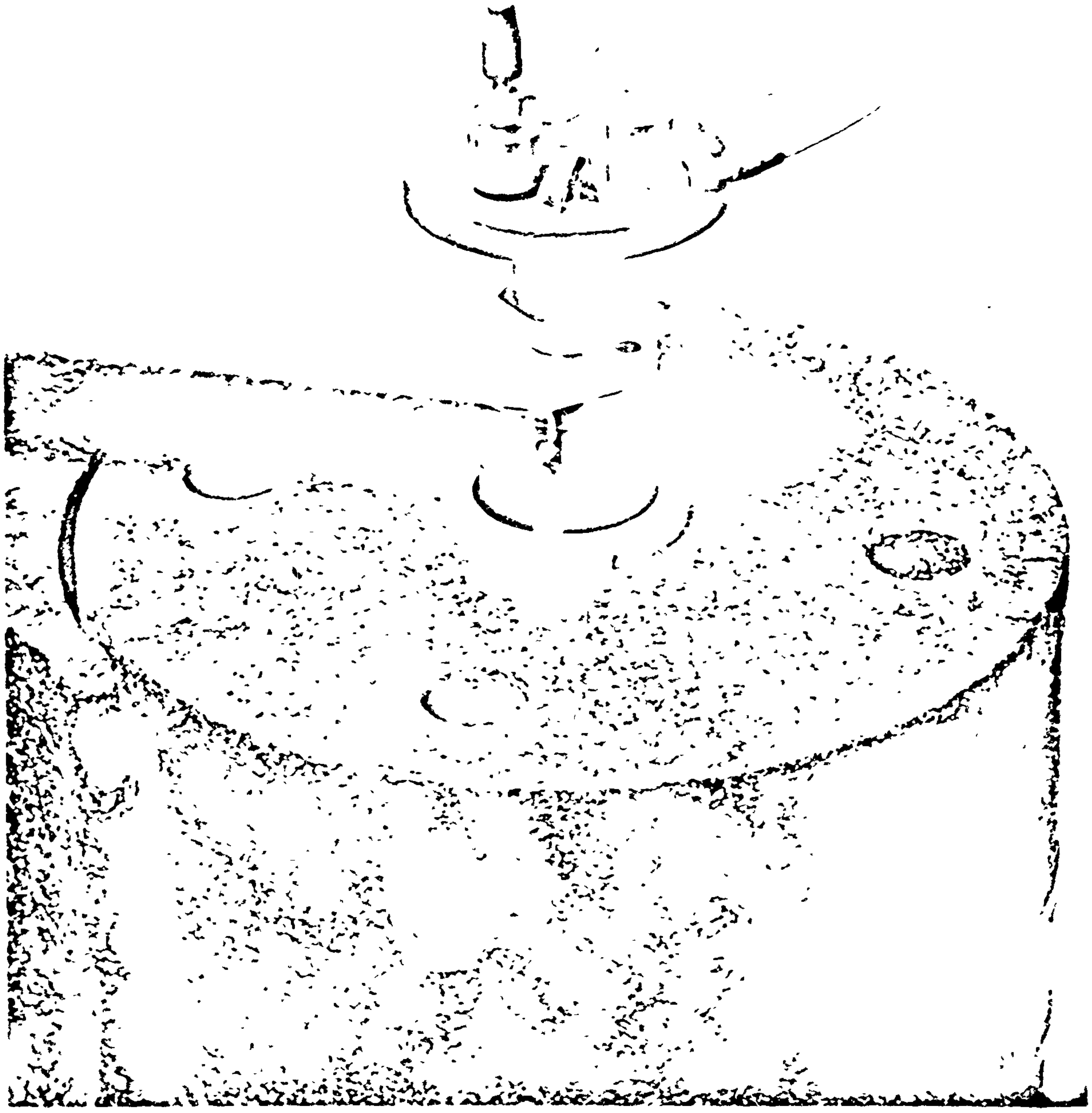


Figure 17. Calydine Table With Transducer Between Two Accelerometers.

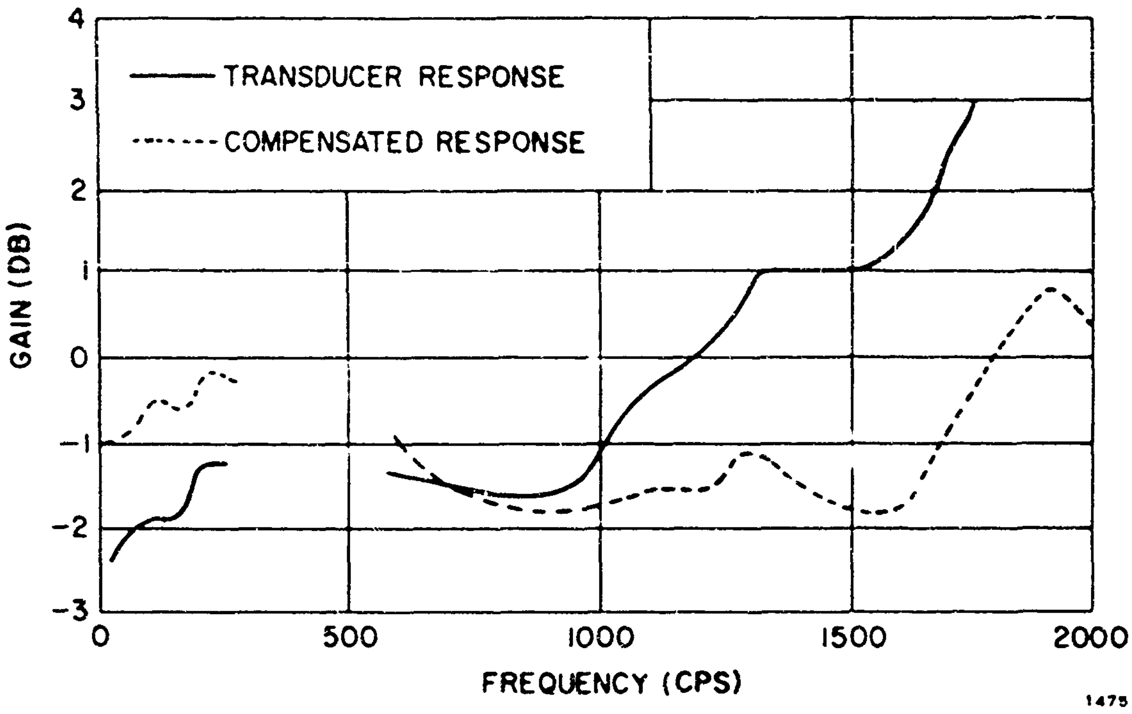


Figure 18. Transducer Response No. 1.

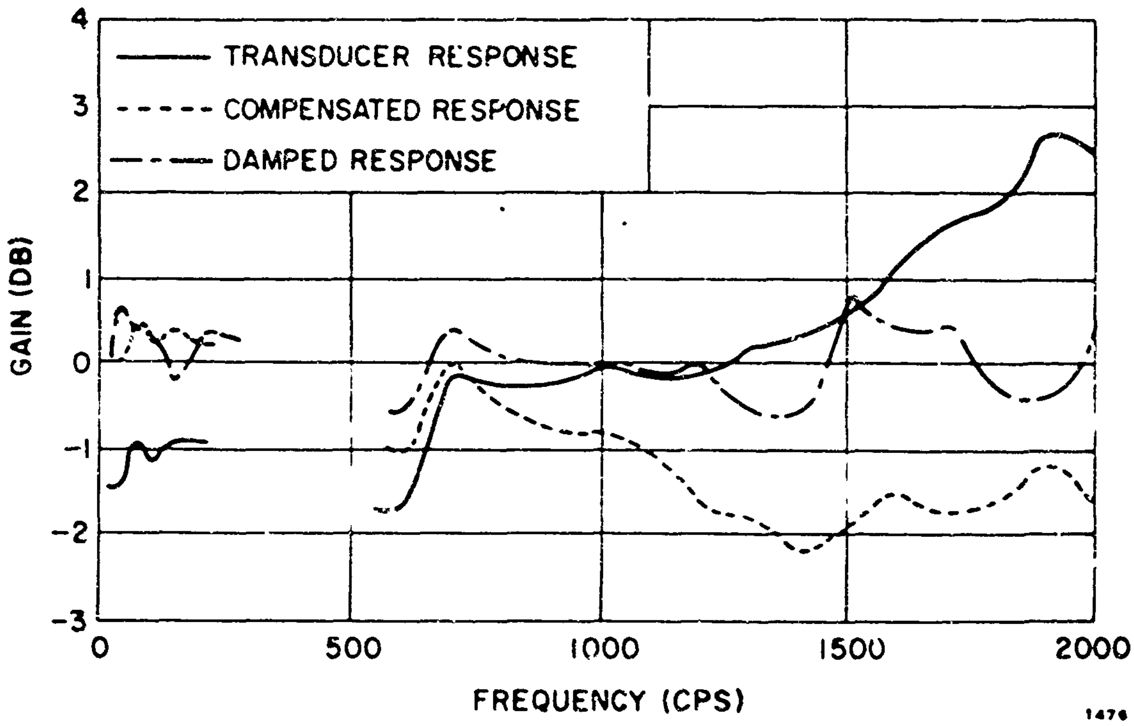


Figure 19. Transducer Response No. 2.

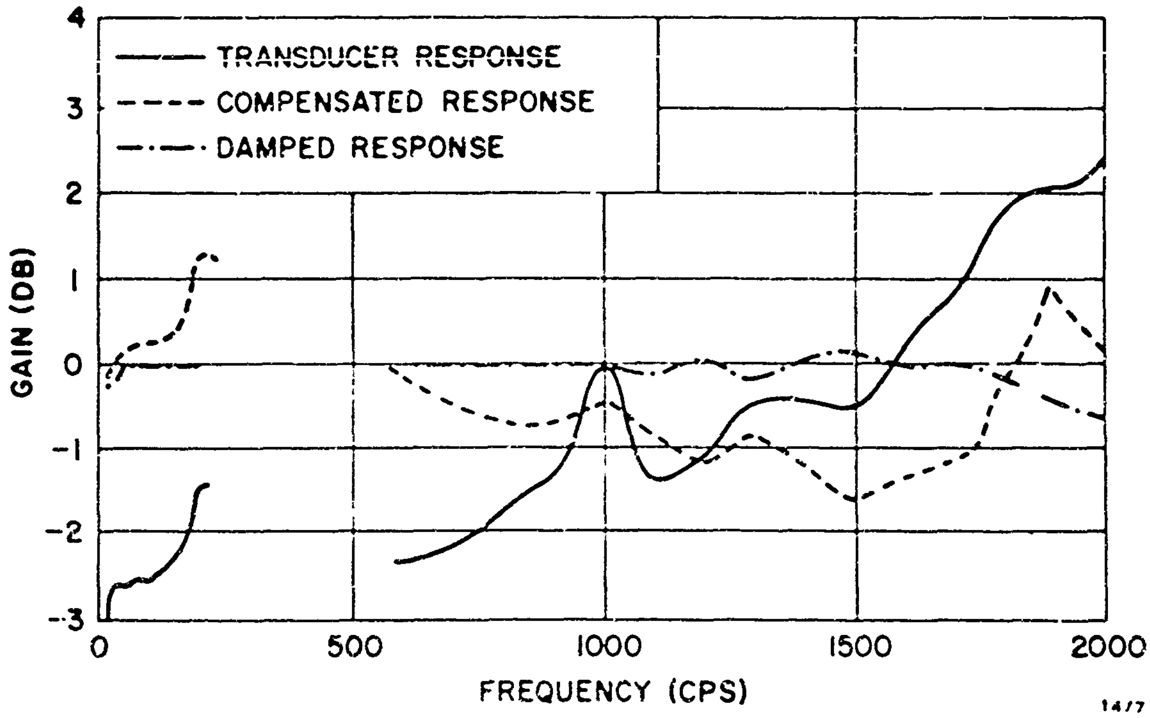


Figure 20. Transducer Response No. 3.

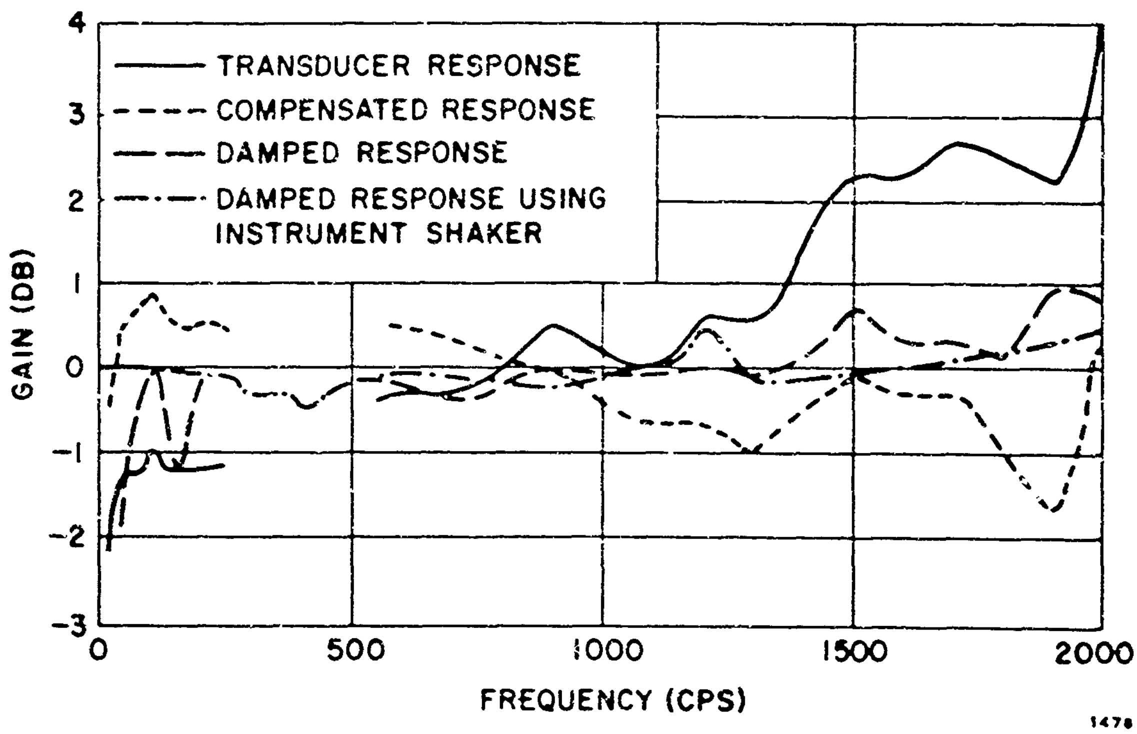


Figure 21. Transducer Response No. 4.

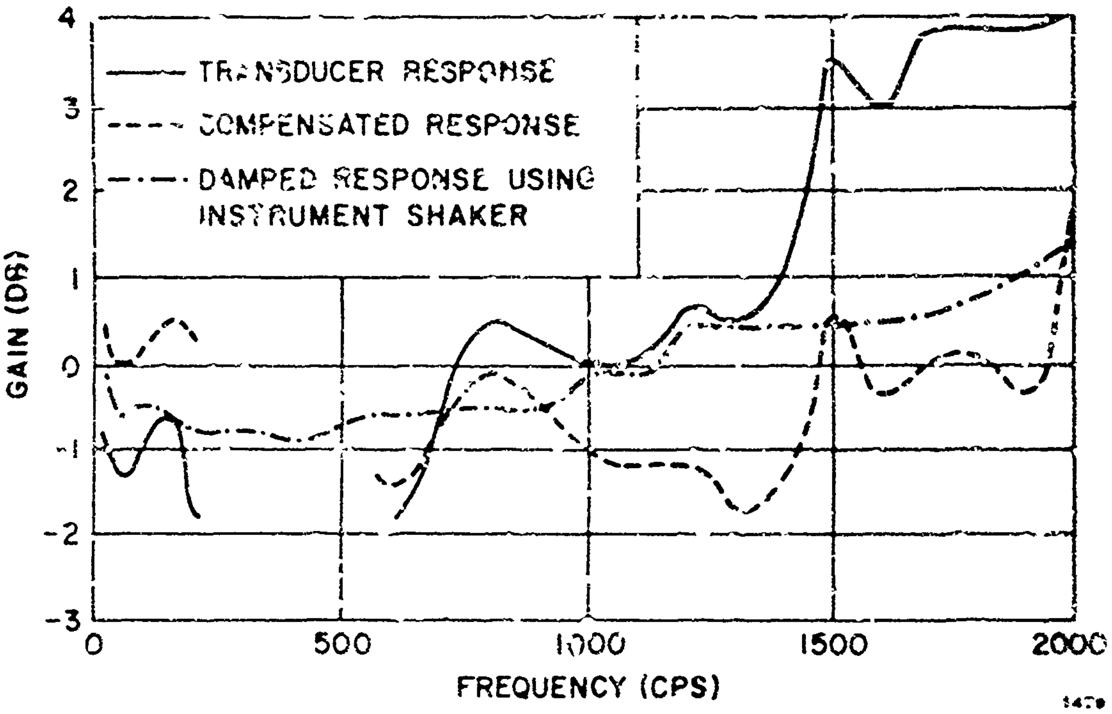


Figure 22. Transducer Response No. 5.

Since the best results in reducing the distortion had occurred with the transducer using the silicone fluid as a damping agent (this design is discussed in the preceding semiannual report), it was decided to follow a similar approach. The silicone fluid was replaced by small neoprene blocks (Figure 23) which were located at the free end of the crystal. The output during vibration was again reduced to an impractical extreme. These two insertions were then moved to approximately the center of the crystal, as can be seen in the same figure. Although the distortion caused by subharmonics of the mechanical resonant frequency was not completely eliminated, it was reduced to an acceptable level. With respect to the frequency response, the variation was less than ±2 db. Even though the addition of the damping material caused a decrease from the original output which was in the neighborhood of 10 to 14 mv/g, the sensitivity of the final assembly remained above 4 mv/g at the normalizing frequency. Comparison of results between the 2g and 4g level inputs indicates that the linearity in the output is well within the tolerable ±10 percent limits. In many instances the linearity deviation is less than 2 percent. With this particular design, all of the originally intended specifications had been achieved.

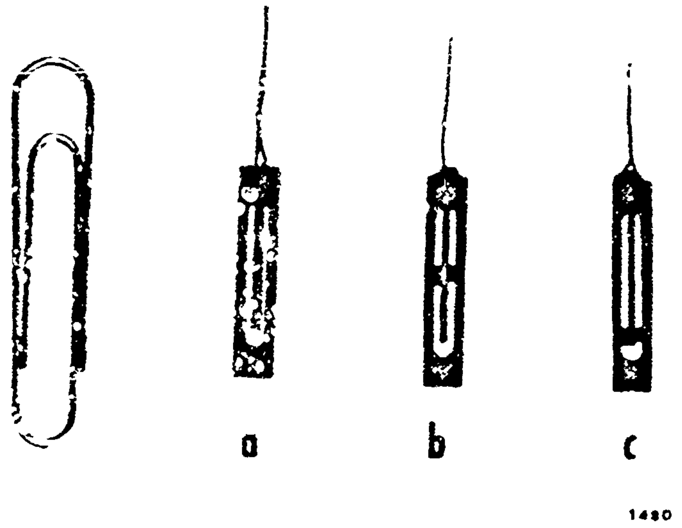


Figure 23 Transducer Without Neoprene Material (a) and Transducers With Neoprene Blocks (b and c).

To substantiate the result obtained from this first transducer with neoprene insertions, data were obtained from three other transducers which had previously been fabricated for the compensated response test. By simply inserting the neoprene blocks in place, these units were ready for testing. Data obtained from these three transducers were plotted on the same respective graphs as the data which had been obtained when using the filter network (see Figures 19, 20, and 21). This allows a better comparison of the normal output, the compensated response, and the neoprene damped output. As seen in the curves, the frequency response variation remained within ±1 db over the frequency range which was used for testing on the Calydine table. This was more of an improvement than had been anticipated. To support this evidence, and to obtain data in the frequency range for which the Calydine table was not acceptable, one of the transducers was placed on a precision Goodman instrument shaker. The shaker output was monitored with a secondary standard to confirm the acceptability of transducer vibration input. These data are plotted in Figure 21 along with data received from three previous tests performed on the same transducer. As seen in the graph, the frequency response is more than satisfactory for the intended purpose. When using the Goodman calibration

shaker as the driving source, observations of the transducer output waveform on an oscilloscope revealed only a slight distortion. Also tested on this instrument table was the transducer having the highest variation in upper frequency response. When testing the normal response of this transducer, a 6-db gain over the response at the normalizing frequency resulted at 2000 cps. Even with a rise in response this great, the neoprene insertions reduced the output to a +1.5 db gain at 2000 cps, which is within the tolerable limits The data from this last transducer were plotted with the data obtained from the transducer using the filter method (Figure 22). As mentioned before, the rapid variations obtained on the Calydine table were caused by input distortion. The curve labeled "compensated response" remained within the tolerable limits, but distortion was not sufficiently reduced.

This final transducer design meets the original requirements of the lightweight transducer. It is extremely lightweight (approximately 0.35 gram), and can be quickly and easily secured in place using an adhesive cement such as Eastman No. 910. Also, this design has a ensitivity of at least 4 mv/g, which may possibly be increased. Linearity is well within 10 percent and might, under uniform fabrication methods, approach a figure of less than 3 percent. The size of the unit allows dynamic measurements in locations previously prohibited by larger commercial accelerometers. A repeatable frequency response remaining within ±1.5 db can be achieved with this transducer. Economically, it is expendable; the barium titanate crystals cost only $1.00 each, and the housing can be made by a punching process for even less. Though these transducers are fragile with respect to lead and crystal damage, sufficient precaution can reduce the breakage to a negligible amount.

Since the requirements of this project have been accomplished, added time and expense to further improve the lightweight transducer were not justified. It is felt, however, that varying the type of material of the insertion, and shifting its location with respect to the active element, would result in a low-cost, lightweight, expendable transducer that could be used in many vibration monitoring applications where the above features with reasonable response are desirable, and where precision accuracy is not essential.

VII. FOAMED-IN-PLACE PROGRAM

Recognizing the importance of the development of new materials to progress in design techniques, the Materials and Processes Laboratory has continued with its investigation of a number of commercially available foamed-in-place materials. The materials are as follows:

a) Nopco Lockfoam A210
b) Nopco Lockfoam F504
c) Nopco Lockfoam BH610
d) American Latex Stafoam 310
e) American Latex Stafoam 410
f) Emerson and Cuming Eccofoam FP/12-6
g) Minnesota Mining and Manufacturing Scotchcast 603
h) Chase Nafil AR-10.

The purpose of experiments with these materials was primarily to determine their maximum reactive exothermic temperatures, and to study the corrosive effects of the foam systems on electronic equipment.

A. Temperature

In regard to the first concern of investigation, it was found that, except for American Latex Stafoam 310, the exothermic reaction in volumes of 16 cubic inches and smaller is below the maximum allowable operating temperature for thermally sensitive semiconductors in all the foam systems.

Nopco Lockfoam BH610 and Minnesota Mining and Manufacturing Scotchcast 603 (formerly Minneapolis-Honeywell Sealfoam 603) build up to a temperature close to maximum operating temperatures, yet remain well below the maximum allowable storage temperature. In the 32-cubic-inch volume reaction, Nopco Lockfoam BH610 exhibits a very high temperature build-up, while the temperature attained by Nopco Lockfoam A210, American Latex Stafoam 310, Stafoam 410, and Minnesota Mining and Manufacturing Scotchcast 603 remains above the maximum allowable for semiconductors. However, of the materials tested, only one reacts with a temperature low enough to be useful as a foamed-in-place packaging material for semiconductors. This judgment is based on an 88°C maximum allowable temperature and a 48-cubic-inch foam volume.

This last fact is of considerable importance, since the exothermic reaction temperatures increase as the volume increases. Thus, components packaged in volumes over 48 cubic inches must be carefully examined. For example, 64 cubic inches of Nopco Lockfoam BH610 produced approximately 190°C at the center of the foaming mass.

B. Thermal Transmission

Thermal transmission data have been obtained on the foams mentioned above. Conclusions reached are as follows:

1) Though Chase Chemical Nafil AR-10 was a satisfactory thermal insulator, Nopco Lockfoam BH610 and American Latex Stafoam 310 were found to be better.

2) Where thermal conductivity is of primary importance, Emerson and Cuming Eccofoam FP/12-6 is best, followed by Minnesota Mining and Manufacturing Scotchcast 603 and Nopco Lockfoam A210.

At the present time, several other projects are under way. For example, samples are currently being prepared from each of the foam systems for use in compression deflection, heat distortion, and heat resistance tests to be performed at 150°, 200°, and 250°F.

C. Corrosiveness

The Materials and Processes Laboratory also performed an investigation of the effects of corrosiveness on electronic materials. As was detailed in the last semiannual report, the test assemblies consist of electronic materials embedded in 1 by 2 by 2-inch blocks of foam and exposed for a period of 90 days to the following environments:

1) Room temperature, uncontrolled humidity, and 100 percent relative humidity

2) 130°F, uncontrolled humidity, and 100 percent relative humidity

3) 185°F, uncontrolled humidity, and 100 percent relative humidity.

Tests have been completed on all the foams under study. Though slight tarnishing of metal parts and yellowing of foam was seen on assemblies exposed to elevated temperatures, there was no evidence of corrosion on electronic circuit materials by any of the foams in dry (uncontrolled humidity) condition.

Finally, it was found that assemblies exposed to high relative humidity were most affected at a temperature of 185°F. Metal parts were pitted, and the foams were black and shrunken. However, at temperatures of 130°F, and room ambient with 100 percent relative humidity, only slight pitting of metal parts and yellowing of foam were observed.

VIII. MICROMINIATURIZATION

At the present time, the study of microminiaturization is in the incipient stages. Work has begun, however, with the immediate goal of determining the state-of-the-art. A questionnaire, requesting information concerning the nature and magnitude of development in microminiaturization, was sent from STL to 55 organizations. Of these, 35 have been returned, and they reveal that a great deal of work is under way in the field.

The organizations which returned questionnaires have all invited representatives from STL to visit their laboratories and review their work. A trip to the principal centers of activity to gather technical data and to determine the applicability of the art to future missile development is now being planned. At the same time, considerable technical information has already been received and is now being reviewed.

IX. WELDED WIRE CONNECTIONS IN ELECTRONIC ASSEMBLIES

Some of the contractors for the ballistic missile program have proposed the use of welded wire connections in electronic assemblies. For years, in the vacuum tube manufacturing industry, this technique was used to great advantage. Its use in electronics assembly is, however, a new application.

Field trips to various manufacturers have been made by members of the Materials and Processes Laboratory to determine the state-of-the-art on the

welded joint method. To date, findings have been promising. Among the advantages cited as being offered by the method are:

a) High component densities
b) Miniaturization
c) Weight savings
d) Improved reliability.

It is planned to make a study of the currently available welding machines to determine which machines could be used for a study program at STL. Such a study would entail operating parameter determinations, machine limitations, and prototype fabrication. An important element of the study would be to determine the uniformity and the degree of attainable reliability of the welds when this method is used to interconnect components in electric equipment.

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